Chaos Modulation by Mach-Zehnder Interferometer

Rabab K. Al Khafaji[1], Kais A.M. Al Naimee[2]

[1,2]Department of Physics, College of Science , University of Baghdad, Al Jadiriah , Baghdad , Iraq
[2]CNR-Istituto Nazionale di Ottica, Largo E Fermi 6, 50125 Firenze, Italy

Abstract— *We report an experimental evidence of the generation of spiking in semiconductor laser (SL) with optoelectronic feedback (OEFD) using Mach-Zehnder modulator (MZM). The chaotic optical output of SL has been modulated by an external periodic perturbation with different frequencies (0 -110) MHz range. Two white noise-induced phenomena, the coherence resonance (CR) and the stochastic resonance (SR) have been studied at chaotic laser output. The noise intensity range -36 dBm to12 dBm has been utilized,. In SR, periodic signal with constant frequency 500 KHz and different noise level from (-36 dBm to12 dBm) have been applied as a control parameter in this condition.*

Keywords— Chaos, feedback, Mach-Zehnder Modulator (MZM), coherence resonance, stochastic resonance.

I. INTRODUCTION

The term Chaos is a paradigmatic name used to describe deterministic dynamical systems whose behavior is complex, unpredictable and extremely sensitive to initial conditions [1,2].Sensitive dependence on initial conditions means that if two chaotic temporal sequences start from very close but slightly different initial conditions, the two sequences behave similarly at the beginning, however, they start to diverge exponentially in time and never show the same behavior again [3].

Irregular spiking sequences in biological, chemical, and electronic systems have been frequently observed to be the result of multiple time scale dynamics. Indeed, a variety of natural systems showing this behavior (neural cells , cardiac tissues , chemical reactions , to name just a few) can be mathematically described by means of slow and fast variables coupled together (slow-fast systems). The chaotic spiking regime can be understood in terms of excitability of a chaotic attractor, where the small chaotic background spontaneously triggers excitable spikes in an erratic but deterministic sequence [4].When a semiconductor (SL) is subjected to one or more perturbations such as Optical feedback (OFB), Optical injection (OI), Optoelectronic feedback (OEFB) and optical modulation, it can display rich nonlinear dynamics including chaos [5]. A Mach-Zehnder interferometer (MZI) is the source of nonlinearity while the semiconductor laser that provides the optical power acts as a linear current-to-optical frequency converter. The nonlinearity of the interferometer coupled with the delay in the feedback loop combine to produce a range of steady state, periodic, and chaotic behavior [6].white noise is a random signal with a constant power spectral density [7].The response of dynamical system to noise has attracted large attention recently. There are many examples demonstrated that noise can lead to more order in the dynamics. To be mentioned are the effects of noise induced order in chaotic dynamics [8]. Coherence resonance (CR) refers to coherent motion stimulated by noise on the intrinsic dynamics of the system without the presence of an external periodic forcing [9], (i.e.) noise can induce and optimize the temporal regularity of the system dynamics, regardless of the presence of any external signal.

Stochastic resonance (SR) is probably the most famous and established effect among noise-induced phenomena. SR can be defined as an enhancement of the regularity of a system output for certain range of noise amplitudes when the system is driven by a weak periodic signal. In fact, the system is helped by noise to follow the frequency of the periodic signal in a resonance-like behavior [10]. SR describes the improved synchronization of the system output with the input due to an intermediate and optimal noise intensity.SR refers to a generic physical phenomenon typical for nonlinear systems in which one of the characteristic time scales is controlled by noise [11,12].

The work aims to study the CR and the SR in chaotic laser output. The SL has been coupled to the MZM as in a feedback arm. Studying the external periodic perturbation effect on the system chaotic output. This method could be invested in a secure communication.

II. THE EXPERIMENT

The experimental configuration illustrate in figure(1) its consist of semiconductor laser(SL), Mach-Zehnder Modulator(MZM), photodetector(PD) and amplifier. MZM is a device used to determine relative phase shift between two collimated beams from a coherent light source either by changing length of one of the arms or by placing a sample in path of one of the beams. MZM has two input ports and two output ports. A basic MZM is constructed using two couplers, one at the

input acts as splitter and another at the output acts as combiner. The light is split in the two arms of the interferometer by the input coupler and recombined at the output by the output coupler. The optical path length of two arms is unequal making the phase shift corresponding to delay to be a function of wavelength of the input signal [13] .

The chaotic behavior of optoelectronic feedback (OEFB) is investigated under the effects of the bias voltage of MZM as control parameter. A Schematic of the experimental setup for investigating of chaotic behavior in MZM with OEFB. SL(1310nm) is coupled to the MZM then into photodetector(PD) to convert the optical signal to electrical signal, the PD is coupled into the amplifier then to the arm of the feedback.

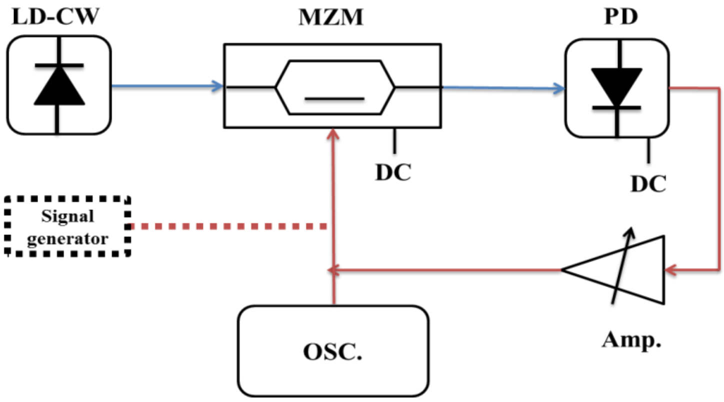


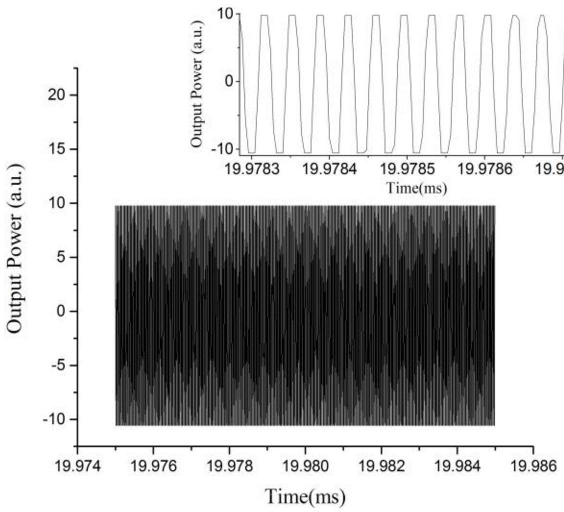
FIGURE 1 ILLUSTRATION THE EXPERIMENTAL CONFIGURATION WHERE BLUE LINES REPRESENT OPTICAL PART AND RED LINES REPRESENT ELECTRICAL PART.

2.1 Chaotic modulation

We introduce the frequency on the feedback arm of the dynamical system using external periodic perturbation (0-110) MHz. Dashed line represents the source of periodic external perturbation shows the experimental setup of chaos modulation.

As in figure 2 with high amplitude 1 dBm of perturbation signal and low amplitude 0.2 dBm in figure 3, in this condition modulation frequencies(28,30,40 and 50) MHz appear always when its level either high or low. When we test these frequencies (28,30,40 and 50)MHz by plotting the bifurcation diagram we notice that the frequency 28 MHz will be coherency approved as shown in figure4.

Figures 5 shows the Power spectra of anther modulated frequencies (60,70,80,90 and 100)MHz with high amplitude 1 dBm. By decreeing their amplitude to 0.2 dBm we noticed that the power spectra of these frequencies was successfully hide within chaotic signal with a highly masking degree as shown in figure 6. Figure 7 shows the maxima recordings of the intensity of laser as a function of the frequency (Bifurcation diagram).



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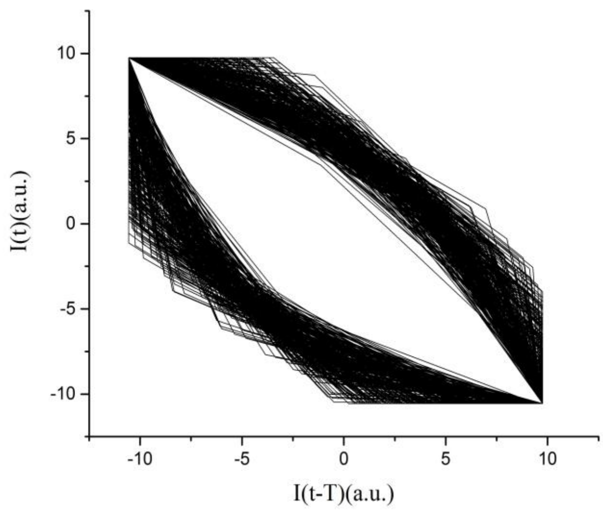

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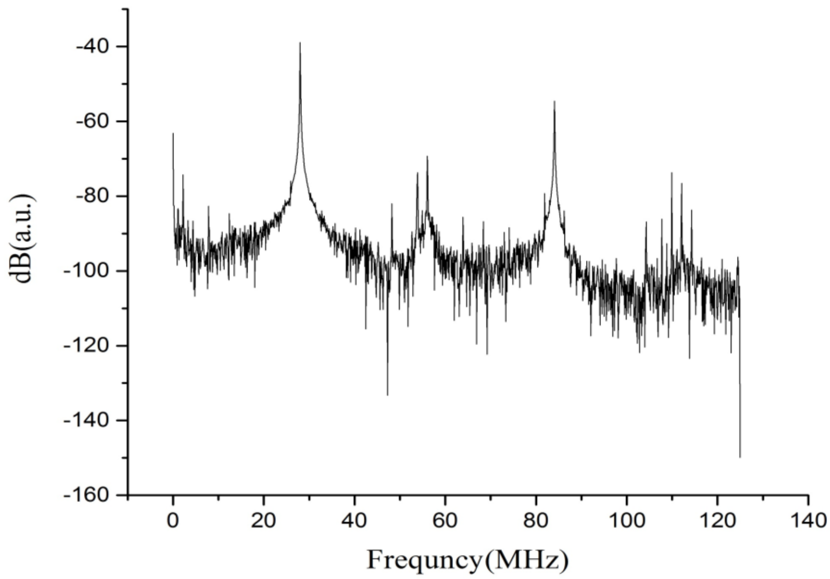


(C)

FIGURE 2: (A) EXPERIMENTAL TIME SERIES OF SYSTEM WITH MODULATION FREQUENCY28 MHz WITH HIGH AMPLITUDE 1 dBm, (B) THE CORRESPONDING ATTRACTOR, (C) THE CORRESPONDING FFT.

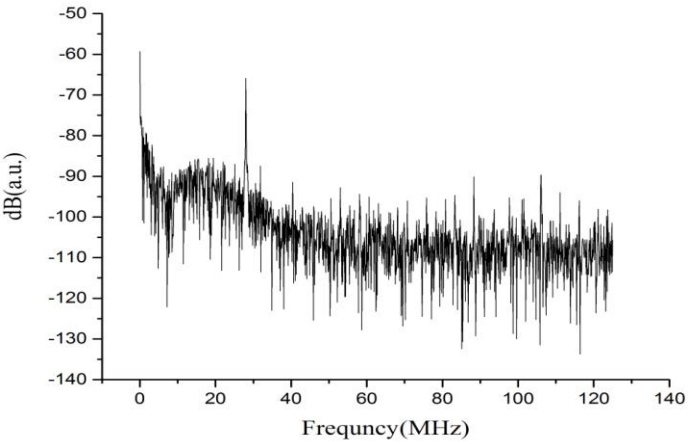


FIGURE 3: POWER SPECTRA WITH HIDDEN MODULATION FREQUENCY 28 MHz WITH LOW AMPLITUDE 0.2dBm.

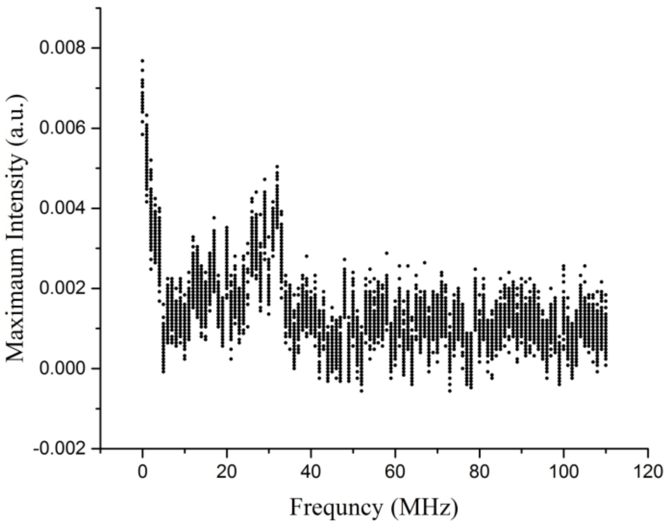
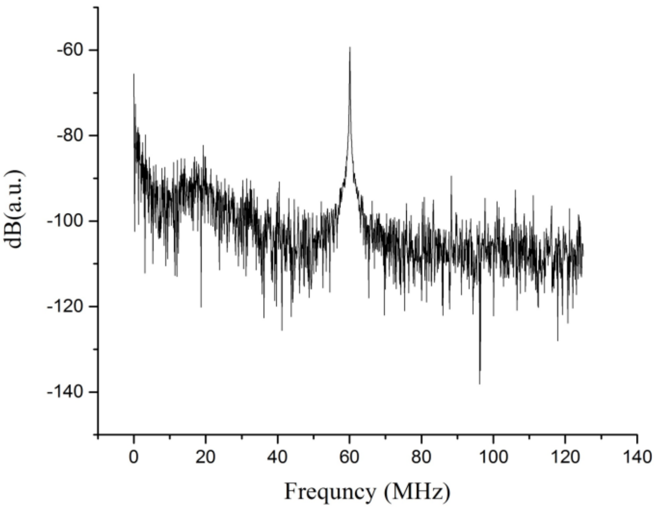


FIGURE 4: MAXIMUM INTENSITY AS A FUNCTION OF FREQUNCY.



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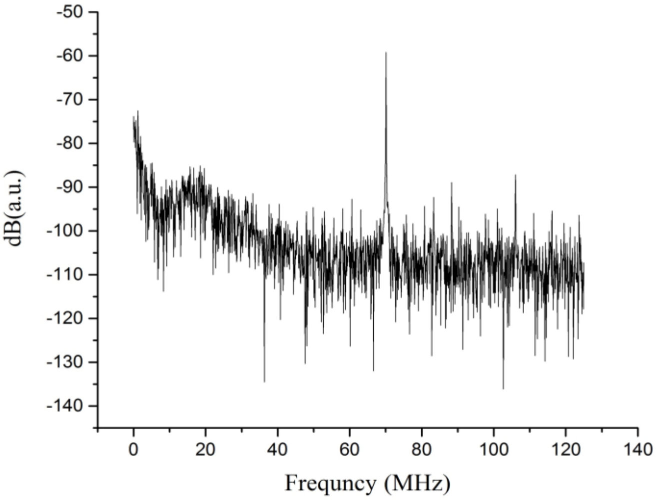

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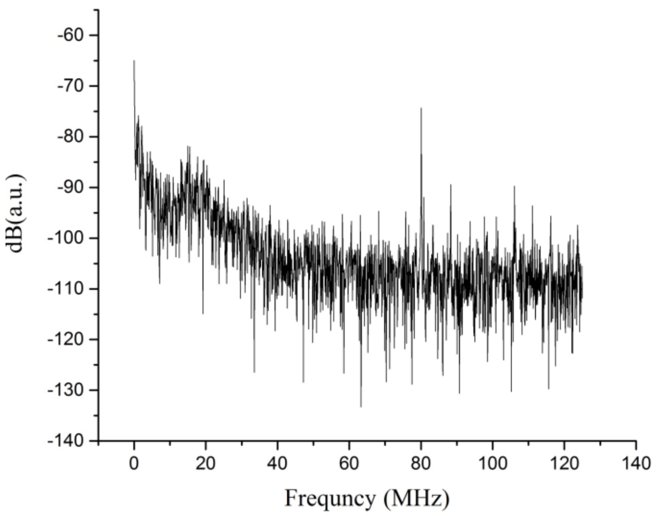

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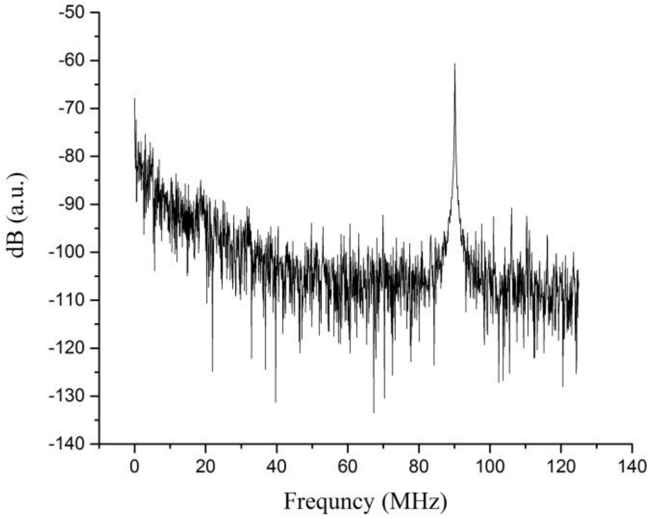

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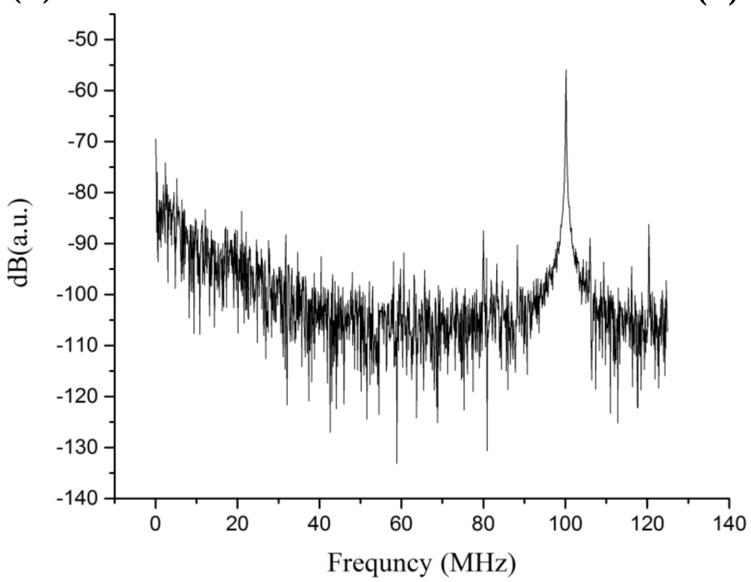


(E)

FIGURE 5: POWER SPECTRA WITH DIFFERENT APPEAR MODULATION FREQUENCIES (A) 60MHZ , (B) 70MHZ, (C) 80MHZ, (D) 90MHZ AND(E) 100MHZWITH HIGH AMPLITUDE 1 DBM.

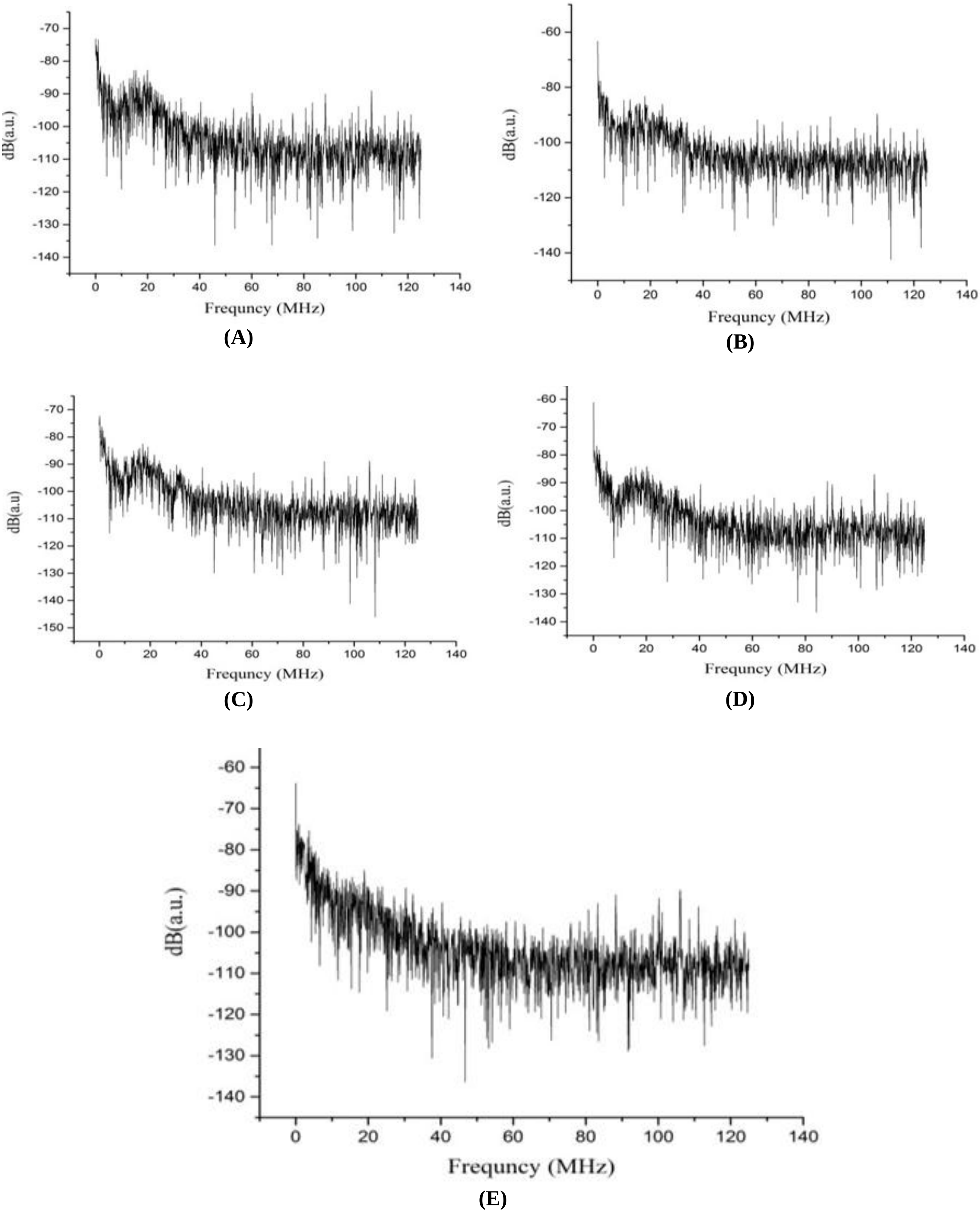


FIGURE 6: POWER SPECTRA WITH DIFFERENT HIDDEN MODULATION FREQUENCIES (A) 60MHZ , (B) 70MHZ, (C) 80MHZ, (D) 90MHZ AND(E) 100MHZWITH LOW AMPLITUDE 0.2 dBm.

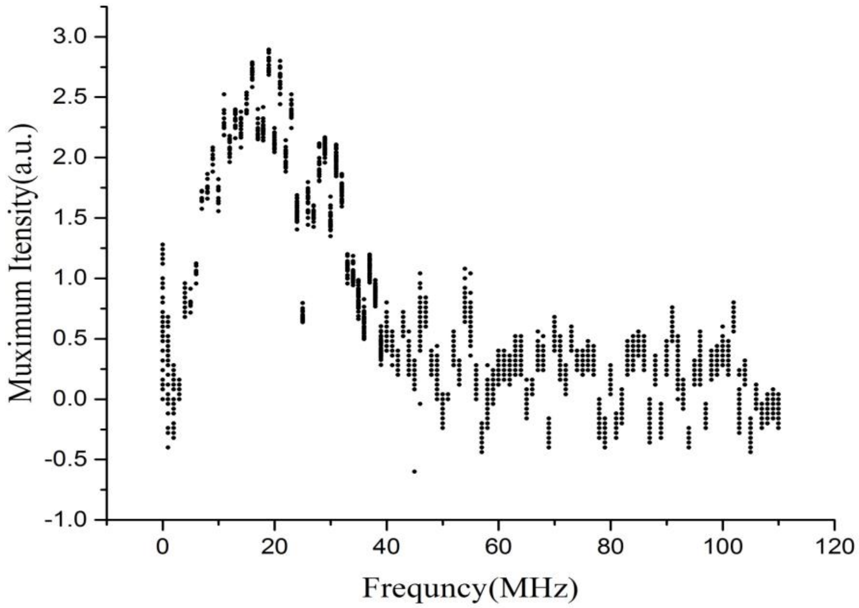
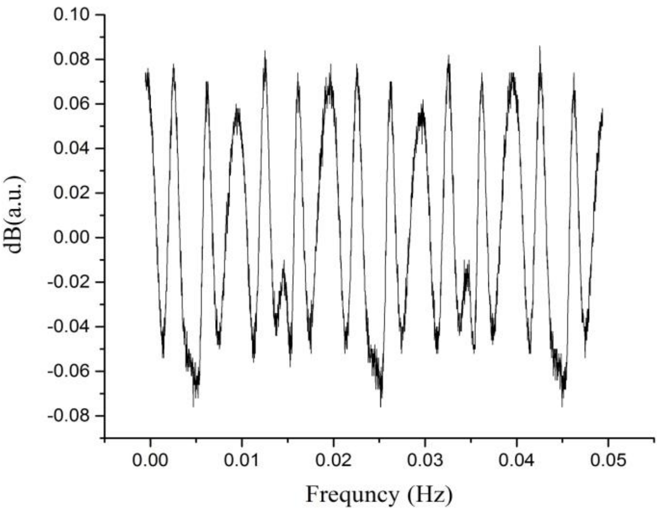


FIGURE 7: EXPERIMENTAL BIFURCATION DIAGRAM OF THE LASER INTENSITY AS A FUNCTION OF THE FREQUENCY MODULATION.

2.2 Coherence Resonance

Instead of signal generator the noise generator has been replaced for studying coherence resonance (CR).A white noise has been utilized for this purpose. Where the range of the noise level D from -36 dBm to 12 dBm. when we begin to change the control parameter (D),the spikes become more frequent , Figure 8a at D = -35 dBm the behavior becomes almost periodic and 8b its corresponding attractor .



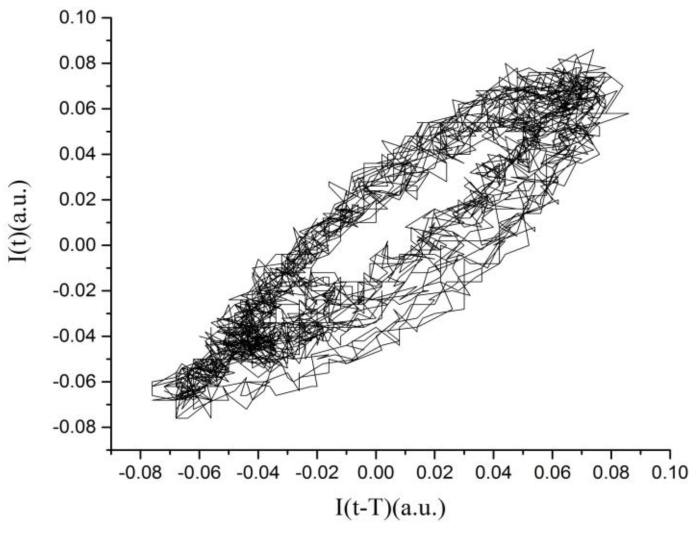


FIGURE 8: (A) EXPERIMENTAL TIME SERIES OF THE SEMICONDUCTOR LASER WITH FEEDBACK, AT NOISE INTENSITY OF D = -35 dBm. (B) THE CORRESPONDING ATTRACTOR.

The bifurcation diagram provides full characterization of the response of our system with white noise level (as in figure9). It is possible to give the summary of results. The small amount of noise intensity from -36dBm to -25dBm produces infrequent dropouts, which become more numerous and regular as the noise amplitude increases into -1 dBm. For high noise strengths spikes become increasingly irregular, both in separation and in amplitude.

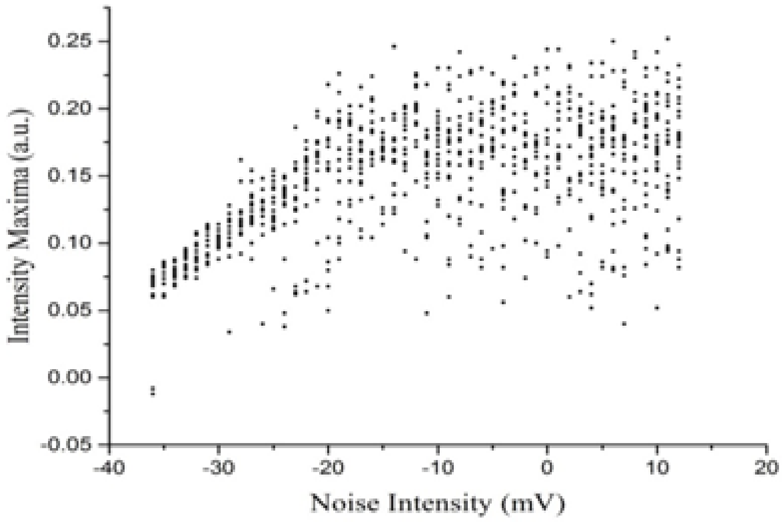


FIGURE 9: THE EXPERIMENTAL BIFURCATION DIAGRAM OF THE LASER INTENSITY AS A FUNCTION OF THE NOISE INTENSITY.

2.3 Stochastic Resonance

In this, we have added periodic perturbation at frequency of 500KHz with amplitude of 10mV and white noise to the feedback to achieve the SR as shown in figure10. In this configuration the control parameter is the noise level while the used frequency is a constant.

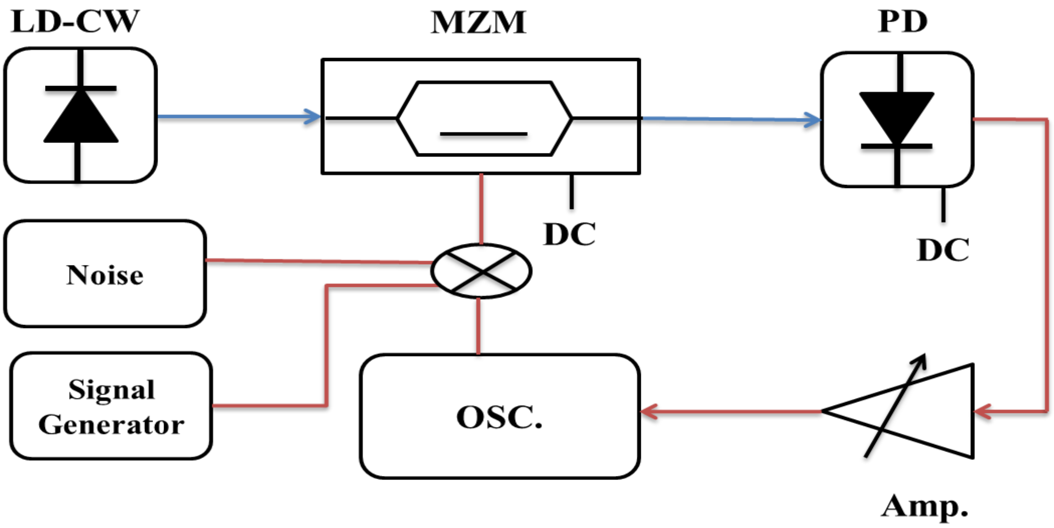
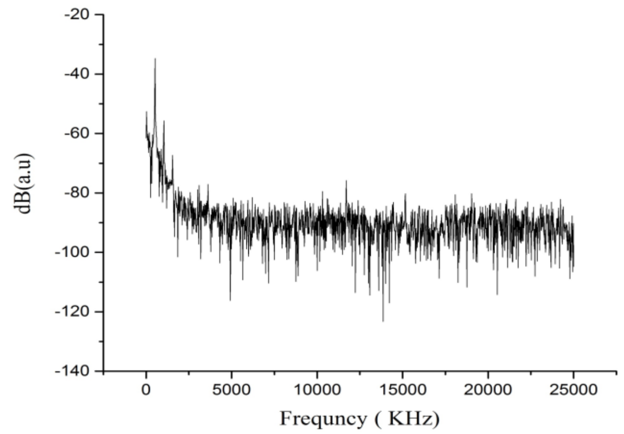


FIGURE 10: EXPERIMENTAL SETUP OF STOCHASTIC RESONANCE WHERE BLUE LINES REPRESENT OPTICAL PART AND RED LINES REPRESENT ELECTRICAL PART.

Adding the noise with the periodic perturpation to the pumping current is able to enhance the regularity of the dropout time series emitted by the laser, extracting an internal time scale defined by the characteristic excursion time mentioned above. The power spectra of different noise levels was analyzed, observing a sharp peak at the modulation period for certain noise levels as shown in figure 11. The sinusoidal signal appear in the power spectrum as a sharp peak when the noise intensity D = -36 dBm, as shown in figure 11a, In figure 11b the amplitude of signal continue to increase with increasing the intensity of the noise into -20 dBm, Until reaches to the maximum at an optimal value of the intensity of noise 10 dBm, at this point the stochastic resonance phenomenon was achieved as shown in figure 11c.



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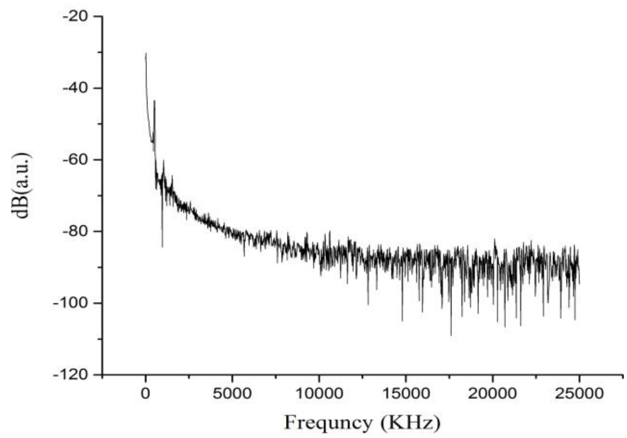

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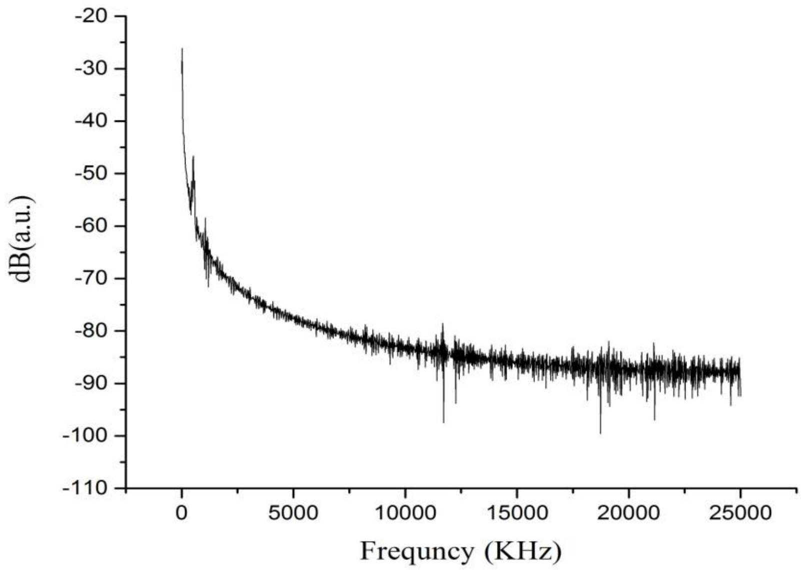

(C)

FIGURE 11 THE POWER SPECTRUM WITH INCREASING VALUES OF NOISE INTENSITY (A,B,C) WITH D=(-36,-20 AND 10)MV RESPECTIVELY AND AN EXTERNAL FREQUENCY OF 500 KHZ.

III. CONCLUSION

To conclude, the bias voltage of MZM acts a good control parameter ingenerating regular and irregular spiking. When the voltage increases, this does not always give chaotic behavior. The different frequencies have been applied as a control parameters, when the chaotic output signal under the effect of the external perturbation, so, the appearance and hidden of these frequencies is achieved for the security of optical communication. From results we noticed that we can't use frequencies (28,30,40 and 50) MHz for security communication because we can't hide these frequencies in both states high and low amplitude.

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